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RESTORATION OF DEFACED MARKINGS USING LOCK-IN INFRARED THERMOGRAPHY

CROSS REFERENCE TO RELATED APPLICATION

This application claims filing benefit of U.S. Provisional Patent Application Ser. No. 62/648,530, having a filing date of Mar. 27, 2018, entitled "Restoration of Defaced Serial Numbers Using Lock-In Infrared Thermography," which is incorporated herein by reference for all purposes.

FEDERAL RESEARCH STATEMENT

This invention was made with Government support under Grant Nos. 2013-R2-CX-K012 and 2015-R2-CX-0017, awarded by the National Institute of Justice. The Government has certain rights in the invention.

BACKGROUND

Marks formed in metal surfaces, such as stamped marks and engraved marks (e.g., laser engraved marks), a prior art example of which is illustrated in FIG. 1 100, provide a means of unique identification for many items including firearms and automobiles. Unfortunately, marks are regularly defaced 110 for criminal activities. However, the marking of the metal surface, e.g., the stamping or engraving process, causes a permanent change in shape of the surrounding metal 102, primarily due to the inability of regions of crystalline arrangement within localized grains to resist the induced stress of stamping, melting, etc., leading to an alteration of the structure and by extension, the interlocking grain boundaries. This resulting deformation extends to some depth below the mark and is known as the zone of plastic strain 104. This area has physical and chemical properties that differ from those of the surrounding non-stamped metal due to the changes in its microstructure.

Many approaches leveraging on these structural features have been developed in an attempt to recover obliterated serial numbers. One widely used approach is chemical etching. This process utilizes the change in chemical potential that makes the defaced area more reactive to acids and thereby allowing for recovery of the defaced number 106 within the zone of plastic strain 104. Chemical etching, however, is a highly controlled and destructive recovery process that requires delicacy and some expertise in applying and removing the etchant. Additionally, because it is a destructive method, the test can only be run once and the test specimen is permanently altered. This shortcoming is the impetus for developing non-destructive, reproducible methods of defaced serial number identification.

A non-destructive approach that has been examined for the detection of defects in metals is infrared thermal imaging. This method seeks to locate and characterize flaws by measuring their effect on heat flow through the material under controlled conditions by observation of the propagation of applied thermal energy. Local regions of plastic strain can be detected as the temperature gradient therein will differ from the rest of the surface due to the local change in thermal conductivity. However, the data acquired through thermographic imaging techniques can be noisy due to undesired signals from several factors including unevenly heated surfaces, radiation from the heated surface and local emissivity variations.

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What are needed in the art are methods for recovering defaced marks in metal surfaces. Non-destructive methods that can consistently recover defaced marks in metal surfaces with high confidence would be of great benefit.

SUMMARY

Disclosed are methods for identifying marks in a defaced metal surface with high confidence. Disclosed methods can include computer-implemented processing of images obtained according to a thermal imaging approach.

In one embodiment, a method can include obtaining a plurality of infrared thermal images of a defaced area on a metal surface by use of a lock-in thermal imaging system. For instance, the plurality of images can include phase images, amplitude images, or both. A method also includes utilizing a computing system to combine data of the phase images and/or amplitude images thus obtained to form an input matrix for the defaced area. For instance, a matrix describing a single phase image or amplitude image, each entry of which includes data from a pixel, can be unfolded and concatenated as a single column of an input matrix for the defaced area. A principal component analysis (PCA) can then be carried out on the input matrix, and a score image constructed for each principal component (PC) obtained from the PCA of the input matrix. Each score image is a reconstruction of a single principal component vector into an image. The score images thus obtained can display the variability in intensity of the different pixels over time during the thermal imaging. One or more of these score images can then be compared to images in a reference data library and based upon the comparison, the defaced mark can be identified, for instance as a single number of a serial number.

In one embodiment, the step of comparing a score image to images of a reference library can include comparison of features that have been extracted from the score image via orthogonal moments, rather than comparing the actual score images. For example, Zernike moments or pseudo Zernike moments can be extracted from the score images. The vectors thus obtained can then be compared to vectors similarly obtained from the reference library data by application of a plurality of similarity measures. The similarity values obtained by application of the similarity measures can then be used to identify the defaced mark, for instance through data fusion of the similarity values for each potential mark followed by ranking the results, e.g., according to a majority vote, a sum rule, or a combination of ranking methodologies.

BRIEF DESCRIPTION OF THE FIGURES

A full and enabling disclosure of the present subject matter, including the best mode thereof to one of ordinary skill in the art, is set forth more particularly in the remainder of the specification, including reference to the accompanying figures in which:

FIG. 1 schematically illustrates a prior art image illustrating a defaced surface and an overlay of an ideal restored image on the defaced surface.

FIG. 2 schematically illustrates a typical lock-in thermography method and system.

FIG. 3 illustrates an exemplary system for carrying out data manipulation and image identification methods as described herein.

FIG. 4 illustrates an exemplary approach for carrying out an image identification process.